536441 Vehicle dynamics and control laboratory

Vehicle's Kinematics Measurement with IMU

This laboratory is design to introduce you to understand and acquire the inertia properties for using in the vehicle handling, stability and ride in a practical environment. It will also provide you with practice in data processing with excel or matlab and writing a technical report representing data and dealing with experimental errors.

The art of car driving is not only a question of having the most highly performable car, but also depends on the skills of the driver and the interaction between the driver and vehicle as well as infrastructure. The applications, such systems are far too costly and complex; however, a GPS aided inertial navigation system (INS) constructed around an off-the-shelf GPS receiver and a low-cost inertial measurement unit (IMU) could provide a lot of information about the behavior of the vehicle, for an acceptable cost. Apart from the direct information (position, velocity, acceleration and attitude) calculated by the GPS aided INS, more indirect information can be extracted as well.

Inertial Measurement unit (IMU) is the unit widely used to refer to box containing three accelerometers and three gyroscopes, optionally three magnetometers and also pressure and temperature. The implementation of inertial sensor such as an **accelerometer** is a device that measures an acceleration or as we know as g-force. Single- and multi-axis models of accelerometer are available to detect magnitude of it. A **gyroscope** is a spinning wheel or disc in which the axis of rotation is free to assume any orientation. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum. Because of this, gyroscopes are useful for measuring or maintaining orientation. Inexpensive vibrating structure gyroscopes manufactured with MEMS technology have become widely available. MEMS gyroscopes are used in automotive roll-over prevention and airbag systems, image stabilization, and have many other potential applications. **Magnetometers** are measurement instruments used for two general purposes: to measure the magnetization of a magnetic material like a ferromagnetic, or to measure the strength and, in some cases, the direction of the magnetic at a point in space. In recent years magnetometers have been miniaturized to the extent that they can be incorporated in integrated circuits at very low cost and are finding increasing use as compasses in consumer devices such as mobile phones and tablet computers.

An inertial measurement unit works by detecting the current rate of acceleration using one or more accelerometers, and detects changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes. And some also include a magnetometer, mostly to assist calibration against orientation drift. Recently, more and more manufacturers also include three magnetometers in IMUs. This allows better performance for dynamic orientation calculation in Attitude and heading reference systems which base on IMUs.

The development in micro-electro-mechanical system (MEMs) technology in recent year has made it possible to fabricate cheap single chip accelerometer and gyro sensors, which have been adopted into many applications where traditionally inertial sensor has been too costly. MEMs sensors have made it possible to construct low cost global navigation satellite system (GNSS) aided inertial navigation system (INS) for monitoring vehicle behavior.

In order to calculate accelerations and velocities in directions of interest (such as fore and aft for performance or left and right for turning behavior), it is necessary to define axis systems to which the accelerations and velocities and the forces/torques causing them can be referred. Since we live in a three-dimensional world, three reference axes at right angles (90°) to each other which meet at a common point (the axis system "origin") are the basic and sufficient requirements for these axis systems. x-y-z are the vehicle coordinate in longitudinal, lateral and vertical respectively accompany with roll pitch and yaw which are the rotation about x, y and z as shown in figure 1

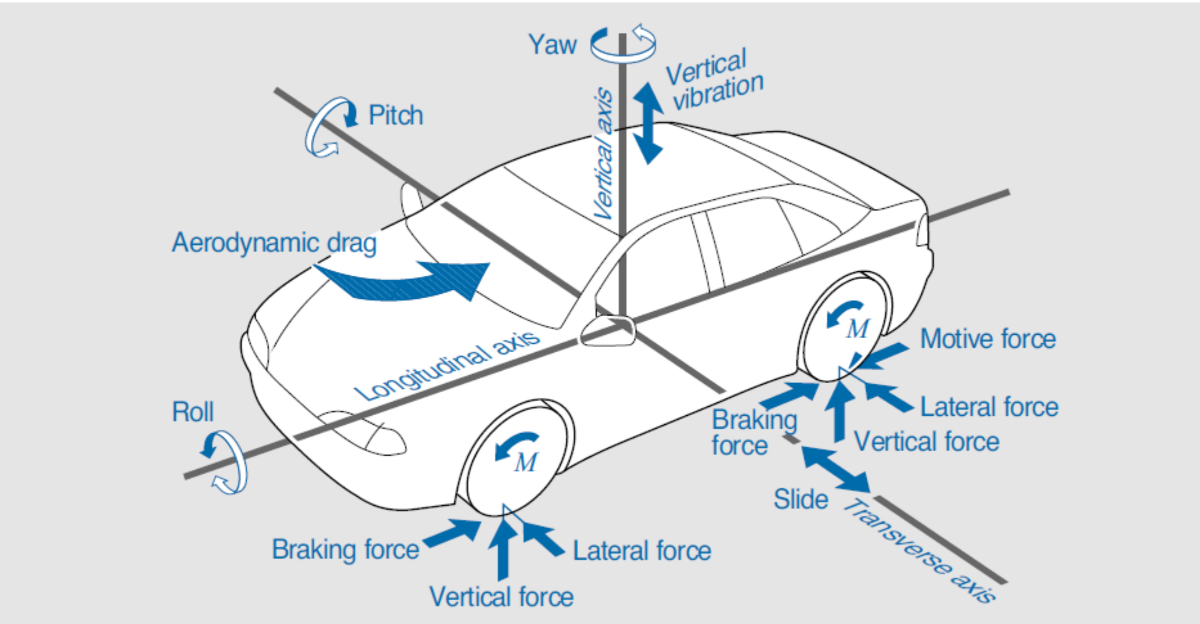

Figure 1 coordinate axis of the vehicle

During the cornering, the simplify bicycle model is chosen to describe the behavior of the vehicle state in figure 2. The so called lateral dynamics model is occurred during turning because of the centripetal force that mostly depend on speed and the path's curvature.

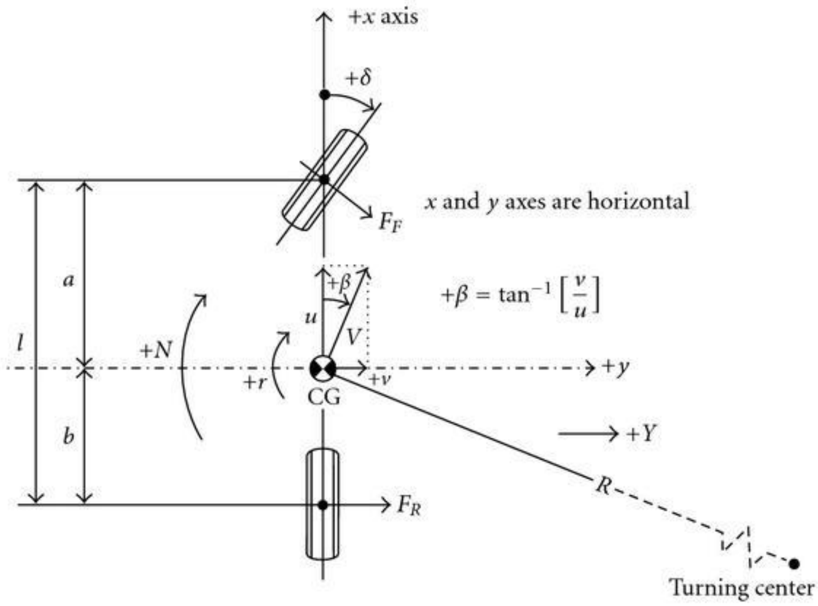

Figure 2 Bicycle model of lateral dyanmics

Test equipment

The Adafriuit 10 DOF IMU (in figure 3) is used for measuring the acceleration, rotation rate, heading, pressure, temperature and altitude. The breakout board allows you to capture distinct types of motion or orientation related data.

This IMU consists of 3 types of chips as,

LSM303DLHC - a **3-axis accelerometer** (up to +/-16g) and a **3-axis magnetometer** (up to+/-8.1 gauss)

L3GD20 - a **3-axis gyroscope** (up to +/-2000 dps)

BMP180 - A **barometric pressure sensor** (300..1100 hPa) that can be used to calculate altitude, with an additional on-board **temperature sensor**

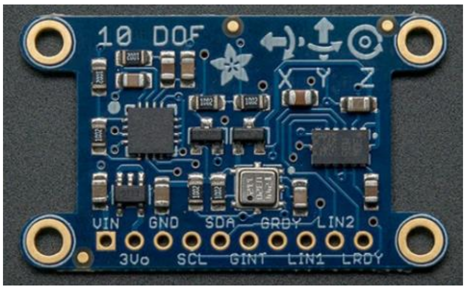

Figure 3 10 DOF IMU

Procedure

Preparing stage:

1. Connecting the IMU with the IO board. For this lab we choose arduino uno basic board function as I/O with following connect pin

Connecting It Up

All of the sensors on the Adafruit 10DOF breakout communicate via a two-pin I2C bus, making it relatively easy to setup with a minimum number of cables:

Table 1 Connecting pins between IMU and Arduino Uno board

Pin on IMU	Pin on Arduino
Vin	Supply Voltage 3.3 Volt
GND	GND
SDA	Analog port 4 (A4)
SCL	Analog port 5 (A5)

2. Inspect the car and make sure that it is ready for driving
3. Mounting the IMU set inside the car in the right axis. The best mounting point should be at CG but if it is not possible try to do the best.
4. Running the program from Arduino IDE. Make sure that you use the correct port and baud rate and then press the serial monitor from Arduino IDE platform. The sampling rate of this measurement is approximately 10 Hz
5. Driving a car. Make sure that you have valid driving license.
6. You must fasten seat belt for all time.

Testing stage:

1. General driving: please feel free to drive anywhere approximately 3-5 kilometers. Collect all data from serial monitor window and copy to excel.

a. Evaluate a_x , a_y , a_z , roll, pitch and yaw. Plot these data versus time and discuss how well you are driving and state the reason.

b. Describe the course e.g. straight, curve, sharp curve, road surface form those.

2. Steady state cornering: try to drive in the constant radius of curvature and constant speed. We should suggest that the speed do not exceed 60 km/h. Collect all data from serial monitor window and copy to excel. For this situation,

   a. Find out the way to calculate the speed of the car. (If you do not have any idea please read the book about kinematics and numerical integration).

   b. Try to calculate the curvature of the path.

   c. Plot all interesting data versus time.

   d. Compare yaw rate from the theory (neglect the slip angle; speed is always tangent to the path) and the real yaw rate from the measurement. Determine whether they are similar or difference manner. Discuss why.

   e. Discuss about the roll rate in this case.

3. Acceleration and Brake: try to accelerate the car as much as possible and then try the hard brake. It should be good if the ABS works. We interested in a_x and pitch.

   a. Calculate the speed of the car over the time.

   b. Plot all interesting data versus time.

   c. Discuss the relation of the acceleration and speed when perform gear shift.

   d. Discuss the deceleration during the brake.

   e. Discuss about the pitch rate in this case.

Further discussion.

1.) Theoretically, the IMU should be mounted at the CG but if it not possible, how can we correct the data.

2.) Normally before each experiments, the IMU must be calibrated. But that's too bad that we did not do it because it is complicated at take times. Please suggest how to calibrate the IMU after mounting.

3.) What is the advantage if we use the heading direction fuse with the data from accelerometer and gyroscope

Note for the data collecting from this program.

Column 1-3 represent a_x , a_y , a_z in m/s^2

Column 4-6 represent roll, pitch , yaw in rad/s

Column 7 is the heading direction calculated from magnetometer. The values vary form 0 to 360 degree like a compass

Column 8 is the pressure in hPa

Column 9 is the temperature in degree celcius

Column 10 is the altitude in meter.

The compensation value of accelerometer and gyroscope are follows:

$a_x = a_x + 0.2$

$a_y = a_y + 0.3$

$a_z = a_z + 0.35$

Roll=Roll+0.07

Pitch=Pitch-0.03

Yaw=Yaw+0

Note on the report

1. It should be concise, informative and contain responses to the tasks a_x
2. Addressing all tasks including abstract and conclusion
3. General presentation is imporatant including well drawn graphs and tables plus sensible use of significant figures
4. Do not repeat or copy anything form this handout. It is not necessary to retype the theories explained in this handout or experimental procedures, just refer to them.
5. Make sure you have the correct units in your results and cauculations
6. Label any tables or graphs and number the pages
7. You can submit the report both in english or thai. Web or programm translation without editing will not be accept!